WHEAT FLOUR AND BREAD

by
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CONTENTS.

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INTRODUCTION.

By far the most important of the vegetable foods in the diet of the American people are the cereals. From the results of some 200 dietary studies, carried on in connection with the cooperative nutrition investigations of the Department of Agriculture among families in widely varying circumstances in different parts of the country, it appears that on an average the different kinds of cereal products together comprised about 22 per cent of the total food and supplied 30 per cent of the total protein, 7 per cent of the total fat, and nearly 55 per cent of the total carbohydrates in the diet.

The cereals in common use are wheat, oats, corn (maize), rye, rice, barley, and buckwheat, the first three being in this country much more important than the others. For the most part they are used in the form of either flour or meal. If the latter term is interpreted broadly it will include the so-called breakfast foods that have lately come into extensive use, as most of them are little more than specially prepared meals. Such foods afford a pleasing variety in the diet, and because of special treatment in their manufacture, often including partial cooking, somewhat simplify the problem of preparation for the table. But of the various forms in which cereal products may be prepared, that which has proved the most universally satisfactory is bread made from rather finely ground meal or flour, and among all civilized people the art of bread making is highly developed.

For several years the nutrition investigations of the Department of Agriculture, particularly those carried on at the Maine and Minnesota experiment stations in cooperation with the Office of Experiment Stations, have included studies of various problems connected with the production of bread and the nutritive value of bread of different kinds. So much has been accomplished in this work that it is believed possible now to draw some definite conclusions from the results obtained. It is the purpose in the present article to consider briefly some of the facts concerning the materials from which bread is made, the changes and losses which occur in the making of bread, and the digestibility, nutritive value, and economy of bread from different grades of wheat flour.

CEREALS USED IN BREAD MAKING.

The simplest kind of bread making consists in mixing the meal or flour with water and baking it, thus producing what is known as unleavened bread, such as the "unleavened bread" of the Jews and the common cracker, or, as called by the English, biscuit. Bread of this nature is dry and hard and, unless baked in a very thin cake, is difficult to masticate. Sometimes in making crackers a little fat (shortening), as butter or lard, is added, and in some kinds baking powders are used to lighten them and improve the texture. The bread most preferred, however, is that which has been raised, or leavened, by producing in the dough a gas that will render it porous. Such bread is light and moist and easy to masticate. A few words will be appropriate here regarding the bread-making properties of the different cereals.

Meal or flour from any of the cereals may be used for unleavened bread, but leavened bread can be made only from those which contain gluten, a mixture of vegetable proteids which when moistened with water becomes viscid, and is tenacious enough to confine the gas produced in the dough. Most cereals, like barley, rice, oats, and corn, some of which are very commonly made into forms of unleavened bread, are deficient or wholly lacking in gluten, and hence can not be used alone for making leavened bread. For the latter purpose rye and wheat, which contain an abundance of gluten, are best fitted, wheat being in this country by far the more commonly used.

Macaroni, vermicelli, and other forms of Italian paste constitute a very important class of foods made from wheat. These do not resemble bread in form, though in food value and in use in the dietary they are very similar to it. Flour paste or dough somewhat similar to that used for crackers is prepared for making these materials, a flour rich in gluten being mixed with water into a paste, which is cut in various forms or pressed into rods, tubes, etc., and is then dried rather than baked. For the finest of these materials a special kind of wheat is preferred, a very hard sort, which has lately assumed importance in this country, and is known best as macaroni wheat.

The grain of rye is to some extent similar to that of wheat, but differs in some important features. It makes darker flour, and its gluten has not the same elastic tenacious quality; hence the rye loaf is not as light and well raised as that of wheat. Rye flour when used alone produces the dark-colored bread which is extensively used in European countries, in many of which it forms the staple article of diet among the poor people, rye flour there being cheaper than wheat. It is commonly regarded as inferior to wheat bread in flavor, but approaches it closely in nutritive value. In the opinion of many persons, rye flour mixed with a considerable proportion of wheat flour makes a much better bread than rye flour alone, and such a mixture is used to some extent in this country.

THE PROCESS OF BREAD MAKING.

(In making unleavened bread the flour is moistened and worked into a stiff dough, which is then rolled, cut into various shapes, and baked, forming a thin, brittle biscuit or cracker.) The process of making raised or leavened bread consists, in brief, in mixing the flour and water in proper proportions for making a stiff dough, together with some salt for seasoning and yeast (or other agent) for leavening. The moistened gluten of the flour forms a viscid, elastic, tenacious mass, which is thoroughly kneaded to distribute the yeast. The dough is then kept in a warm place and the yeast begins to grow, or "work," causing alcoholic fermentation with the production of carbon dioxid gas, which expands the dough, or causes it to "rise," thus rendering it porous. After the yeast has grown sufficiently, the dough is baked in a hot oven, where further fermentation is stopped by the destruction of the yeast by heat, which also causes the gas to expand in the loaf and, in addition, generates steam. The gas and steam inflate the tenacious dough and finally escape into the oven. At the same time the gluten of the dough is hardened by heat, and the mass remains porous and light, while the outer surface is darkened and formed into a crust.

When the flour is of good quality, the dough well prepared, and the bread properly baked, the loaf has certain definite characteristics. Thus, it should be well raised and have a thin, flinty crust, which is not too dark in color nor too tough, but which cracks when broken. The crumb, as the interior of the loaf is called, should be porous, elastic, and of uniform texture, without large holes, and should have a good flavor and odor.

It has already been indicated that gluten is the ingredient of the flour on which its bread-making properties chiefly depend. The important thing is not entirely the quantity of gluten, however, but more particularly its character. Two flours containing the same amounts of carbohydrates and proteid compounds, when converted into bread by exactly the same process, may produce bread of entirely different physical characteristics because of differences in the nature of the gluten in the two samples. All gluten is composed of two bodies called gliadin and glutenin, and the principal factor which determines the character of the gluten is the proportion of gliadin to glutenin in it. The gliadin, a sort of plant gelatin, is the material which binds the flour particles together to form the dough, thus giving it tenacity and adhesiveness; and the glutenin is the material to which the gliadin adheres. If there is an excess of gliadin the dough is soft and sticky, while if there is a deficiency it lacks in expansive powers. Many flours containing a large amount of gluten and total proteid material, and possessing a high nutritive value, do not yield bread of the best

quality because of an imperfect gliadin-glutenin ratio. This question is of much importance in the milling of wheats, especially in the blending of different types of wheat. At the Minnesota experiment station considerable study has been made of this and other problems regarding the bread-making properties of wheat.

Some of the Minnesota experiments were planned to test the question whether it is the starch content or the gluten content that determines the bread-making quality of flour. In certain cases the proportion of starch in a normal flour was increased 10 to 20 per cent by the addition of wheat starch, while in others it was decreased to the same extent, and in still others 10 to 20 per cent of corn flour was added to the wheat flour. In all cases the bread made from the flours containing increased or decreased quantities of starch was compared with that made from a like quantity of the normal flour. In the experiments in which the proportion of starch was increased by adding either wheat starch or corn flour there was practically no difference in either the size or the appearance of the loaf as compared with that from normal flour. The results of these tests, as well as of those made in other countries, clearly indicate that it is the gluten rather than the starch content that determines the bread-making properties of the flour.

Similarly, little difference was observed between the bread from normal flour and that from flour with the proportion of starch diminished. The proportion of starch was diminished, not by removing starch from normal flour, but by adding gluten to it. These tests likewise showed that it is not the starch content that determines the bread-making quality of the flour. They also showed that there is a limit beyond which it is inadvisable to increase the quantity of gluten in flour in order to produce a large-sized loaf. An abnormally large amount of gluten does not yield a correspondingly large loaf.

Experiments were also made to determine the relation between the nature of the gluten and the character of the bread. This was done by comparing bread from normal flour with that from other flour of the same lot, but having part or all of its gliadin extracted. Dough made from the latter was not sticky, but felt like putty, and broke in the same way. The yeast caused the mass to expand a little when first placed in the oven; then the loaf broke apart at the top and decreased in size. When baked it was less than half the size of that from the same weight of normal flour, and decidedly inferior in other respects. It was about as heavy as the same quantity of rubber. The removal of part of the gliadin produced nearly the same effect as the extraction of the whole of it, and even when an equal quantity of normal flour was mixed with that from which part of the gliadin had been extracted the bread was only slightly improved. Similar results were also

obtained at the New Jersey station in experiments with flour from which the gliadin had been extracted. From these experiments it is evident that the bread-making properties of the flour depend upon the nature of the gluten, as any alteration of the character of the gluten or the proportion of its constituents in the flour has a strong influence upon the character of the bread produced. On the other hand, when the character of the gluten or the proportion of its constituents is undisturbed a foreign proteid may be introduced without interfering with the rising of the bread. Thus, in the experiments in which corn flour was added, the proteid of the corn had no effect upon the power of expansion of the normal flour.

In flour of the highest bread-making properties the two constituents, gliadin and glutenin, are present in such proportions as to form a well-balanced gluten. From the data at hand it would appear that for the best results the proper proportion of gliadin to glutenin in hard-wheat flour is about 65 to 35 in 100 parts. Occasionally the percentage of gliadin may fall as low as 55. A large variation from this ratio has a marked influence upon the character of the bread. Advantage is taken of this fact in the milling of wheat when the blending of opposite types, one with high and the other with low gliadin content, is resorted to before grinding in order to improve the quality of the flour.

Flours of different bread-making properties may also be improved by blending after milling. At the Minnesota station experiments were made by combining a hard-wheat flour that had a high gluten content, but was relatively deficient in gliadin, with a soft-wheat flour that had a lower gluten content, but whose gluten contained a high percentage of gliadin, in such proportions that the ratio of gliadin to glutenin in the blended flour was 64 to 36. The hard-wheat flour alone produced as large a loaf as that from the blended flour, but the latter produced the best loaf. The soft-wheat flour produced a soft, sticky dough that expanded while rising but collapsed during the baking, so that the loaf was smaller than the others. These experiments indicated that flours of high food value but poor bread-making properties may be blended so as to produce a better balanced gluten than that contained in either the hard-wheat or soft-wheat flours. The bread produced, however, is not equal in quality to that from wheat normally containing a well-balanced gluten.

In the course of these experiments tests were made of the effect of the temperature of the flour when mixed upon its bread-making properties. In these tests better results were obtained with flour at 70° C. (158° F.) than with flour at a temperature considerably higher or lower. There is, therefore, a reason for the common household practice of warming flour in cold weather before mixing the dough. Care should be taken, however, not to heat the flour too much. In

the experiments referred to, keeping the flour for some time at the highest temperature (100° C. or 212° F.) had a decidedly deleterious effect upon its bread-making properties.

LOSSES OF MATERIAL IN BREAD MAKING.

All processes of bread making entail some loss aside from that of flour and dough accidentally lost in the mixing, but the greatest loss occurs during the production of leavened bread by fermentation. The action of the yeast and the heat at different stages of the process results in the fermentation of carbohydrates and the production of carbon dioxid and alcohol, and other simple bodies from the complex starches, nitrogenous bodies, etc., originally present.

Inasmuch as many of the compounds formed during the fermentation process are either gaseous or volatile at the temperature of baking, there is opportunity for appreciable loss of material. This has such an important bearing upon the nutritive value of flour that considerable study has been made of the kinds and quantities of material lost in bread making. As a result of experiments carried on at the Minnesota and New Jersey stations, it has been estimated that when care is exercised in making bread the amount of nutritive material lost need not exceed 1.5 per cent of that in the flour; but in careless bread making the loss was equal to 8 per cent of the nutritive material of the flour, and it could even be more. The loss in the former case would be equivalent to about 3 pounds of flour per barrel, and in the latter case 15 pounds or more.

This loss affects both protein and carbohydrates to an appreciable extent. Some very careful experiments in bread making, carried on as part of these nutrition investigations in a bakery in Pittsburg, showed an average loss of 1.3 per cent of the total protein and 3.2 per cent of the carbohydrates of the flour in the process. There was also a slight loss of fat, due apparently to its volatilization by the heat of the oven.

Some destruction of protein compounds in bread making is unavoidable when yeast is used, as nitrogenous material is required by the yeast for growth in the process of fermentation, but fortunately it is nonproteid rather than proteid material that is thus utilized, and the amid compounds of the flour, which have practically no nutritive value, may serve to some extent for this purpose.

The loss of carbohydrate material is due chiefly to the formation of alcohol and carbon dioxid by the yeast in growing, both being largely expelled from the bread when it is baked. In addition to these there is also a small amount of carbon lost in other forms, such as volatile acids produced during the fermentation process. As in the case of the nitrogen, some loss of this kind is unavoidable, since the production of

gas to leaven the dough is the object of the fermentation. In these experiments, in which special care was taken in the bread making, the volatile products from carbon given off were equivalent to a loss of 1.68 per cent of the total starch present. It is apparent, then, that the proper course of procedure is to stop the fermentation when sufficient gas has been produced to render the dough as porous as is desired, because further continuation of the process results simply in a destruction of carbohydrates to no purpose.

The important feature of the art of producing leavened bread thus lies in proper fermentation. Unless this process has been allowed to proceed far enough, a heavy, soggy, unappetizing loaf is the result; while if it is allowed to proceed too far there is a considerable loss of material, and an objectionable quality is imparted to the bread by the development of acid.

Several attempts have been made to introduce methods of leavening that would not cause a destruction of nutritive material. One of these is the Dauglish method, by which the so-called aerated bread is produced. This method consists in mixing the flour with water charged with carbon dioxid under pressure. The bread is about as porous as that raised with yeast, but is less agreeable to the taste of many persons, apparently because of a lack of the by-products resulting from the action of the yeast in the fermentation process. Baking powders, that is, mixtures which liberate carbon dioxid when moistened, are used to a considerable extent in making cake and quick-rising breads, biscuits, etc., but the attempts to substitute them entirely for yeast have not met with much success. Some of the objections to them are that they may be easily adulterated, and that bread made by the use of them lacks the flavor and aroma of well-made yeast bread.

THE COMPOSITION OF BREAD.

The composition of bread depends primarily upon that of the flour from which it is made. If milk and butter (or lard) are used in mixing the dough, as is commonly the case, their nutrients are, of course, added to those of the flour; but when only water and flour are used the nutrients of the bread are simply those of the flour. In either case, however, the proportions of the nutrients in the bread are smaller than those in the flour, because a considerable part of the moisture from the water or the milk used in mixing the dough is present in the bread after baking, that is, a pound of the bread would contain less of any of the nutrients than a pound of the flour, because the proportion of water in the bread is greater. The following table shows how the composition of flour compares with that of bread, the different kinds

of bread all having been made from the flour with which they are here compared:

Composition of flour and of bread made from it in different ways.

Material.	Water.	Protein.	Fat.	Carbohydrates.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Flour	10.11	12.47	0.86	76.09	0.47
Bread from flour and water	36.12	9.46	.40	53.70	.32
Bread from flonr, water, and lard	37.70	9.27	1.02	51.70	.31
Bread from flour and skim milk	36.02	10.57	.48	52.63	.30

It is thus shown that the proportion of water is larger and that of each nutrient smaller in bread than in flour, and that the nutrients of the flour are increased by those of nutritive materials added in making the bread.

It is apparent that two kinds of bread from the same lot of flour may differ, according to the method used in making the bread. On the other hand, two loaves of bread made by exactly the same process, but from different lots of flour of the same grade or brand, would not necessarily have the same composition because of a possible variation in the flours. The chemical composition of wheat is not a fixed characteristic, different kinds of wheat varying widely in this respect. Furthermore, the composition of the same sort of wheat varies with several factors, such as climate, rainfall, and the soil on which it is grown. It is evident, therefore, that statements regarding the composition of flour can hardly be definite.

GRAHAM, ENTIRE WHEAT, AND STANDARD PATENT FLOURS.

Inasmuch as the composition of bread is so dependent upon that of the flour, a consideration of the different grades of flour on the market will afford an understanding of how the breads from them compare in this respect. Attention is here given more particularly to Graham, entire wheat, and standard patent flours, as these are the three grades most commonly used, and hence of most importance. Graham flour, strictly speaking, is simply wheat meal, that is, the entire grain ground to a powder. It has sometimes been made by removing the outer branny portions of the kernel and grinding this separately from the inner parts, afterwards combining the two, as it was thought that the efforts to grind the naturally coarse material with the rest of the wheat had a deleterious effect upon the bread-making qualities of the flour. It is now commonly made by crushing and grinding the whole of the kernel at once, without bolting or sifting. When thus prepared it contains the same ingredients as the wheat itself and in the same proportions. Such flour is coarse, however, and even the most

successful attempts at fine grinding still leave it fairly coarse and with a large proportion of branny particles. To overcome this objection more or less bolting is frequently resorted to. Much of the flour sold as Graham has been thus treated, though, of course, such a product is not really Graham flour.

The term "entire wheat" would suggest flour practically identical with the Graham. The flour thus designated, however, it is often said is made by first decorticating the grain, or removing the branny outer covering, and grinding the remainder. By such a method some of the outer portion of the wheat kernel would be retained in the flour, only a small proportion of the wheat being discarded. So far as can be learned some of the so-called whole-wheat flour is not so ground, but is made by including with the patent grades the middling and low-grade flours with considerable of the germ. Whole-wheat flour is not so coarse as Graham nor so fine as the white flours.

The finer grades of patent flour contain neither the bran nor the germ of the wheat. In some of the lower grades the germ is retained, and as this part is somewhat richer than the rest of the kernel in protein, the proportion of this ingredient is larger in the lower than in the higher grades of flour. The chief reason for removing the germ in milling the higher grades is that, because of the presence of the oil, which is more abundant in the germ than in the remainder of the wheat, flour in which it is retained has a tendency to become rancid and to deteriorate in bread-making properties. The bran is left out because of its coarse nature and because it darkens the flour. The grade of white flour most widely used is that known as straight patent, or standard patent, or family grade. Although this flour contains neither the germ nor the bran of the wheat, in modern exhaustive milling nearly 73 per cent of the kernel is recovered in this grade.

Because the proportion of nitrogenous material in both the germ and the outer portions of the wheat is larger than in the remainder of the kernel, it has been popularly contended that the flours from which these portions have been removed are less nutritious than those in which they are retained in the milling. In support of this contention the different grades of flour have frequently been compared with respect to the proportions of protein in them, apparently to the advantage of the coarser grades. In consideration of what has already been shown regarding the variable composition of wheat, however, it is evident that differences in the proportions of nutrients in the different grades of flour as purchased in the market would much more likely be due to differences in the wheat from which they were ground than to advantage in any particular method of milling. Patent flour from wheat with 15 per cent of protein would contain larger proportions of the nutrient than Graham flour from wheat with only 8 per cent, such differences in protein content being not at all uncommon. Obviously,

therefore, the only fair comparison is that between the three grades of flour milled from the same lot of wheat. These points are clearly illustrated by the figures in the following table, perfectly uniform results having been obtained at both the Maine and Minnesota experiment stations:

Composition of flours and breads, as shown by recent experiments.

Material.	Water.	Protein.	Fat.	Carbohydrates.	Ash.
Minnesota wheat flour (fresh material):	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
First patent	10.55	11.08	1.15	76.85	0.37
Second patent	10.49	11.14	1.20	76.75	.42
Standard patent	10.54	11.99	1.61	75.36	.50
First clear	10.13	13.74	2.20	73.13	.80
Second clear	10.08	15.03	3.77	69.37	1.75
"Red dog"	9.17	18.98	7.00	61.37	3.48
Entire wheat	10.81	12.26	2.24	73.67	1.02
Graham	8.61	12.65	2.44	74.58	1.72
Oregon wheat flour (fresh material):					
Standard patent	8.94	7.55	1.25	81.82	.44
Entire wheat	8.66	8.25	1.67	80.35	1.07
Graham	8.15	8.97	1.68	79.48	1.72
Oklahoma wheat flour (fresh material):					
Standard patent	9.93	15.06	.92	73.57	.52
Entire wheat	7.46	16.63	1.64	73.05	1.22
Graham	7.73	16.81	1.79	72.35	1.32
Bread made from Oregon wheat flour (water-free basis):					
Standard patent	....	8.32	1.37	88.93	1.38
Entire wheat	....	9.49	1.82	87.24	1.45
Graham	....	9.94	1.83	85.72	2.51
Bread made from Oklahoma wheat flour (water-free basis):					
Standard patent	....	16.24	1.02	82.03	.71
Entire wheat	....	18.06	1.77	78.75	1.60
Graham	....	18.43	1.94	77.12	2.51
Bread made from patent flour (fresh material):					
High grade	32.9	8.7	1.4	56.5	.5
Standard grade	34.1	9.0	1.3	54.9	.7
Medium grade	39.1	10.6	1.2	48.3	.9
Low grade	40.7	12.6	1.1	44.3	1.3

For the experiments with Minnesota wheat the flours were ground by one of the large mills in Minneapolis. In addition to the three flours under discussion, all the grades of flour commonly ground were produced from this wheat, and obtained for analysis, the results being given in the table. The first patent is the highest grade of flour manufactured; the gluten in it has a greater power of expansion than that in any other grade, and the loaf made is the largest and whitest. Second patent is somewhat similar to first patent, but the gluten has not quite so high a power of expansion, and the bread is a shade darker. The first clear grade, which comprised about 12 per cent of the wheat, is obtained after the first and second patent have been removed. This

grade contains slightly more protein than either of the two patent grades, but the gliadin and glutenin are not present in such favorable proportions for bread making. All three of these flours are combined to produce the straight or standard patent flour. The quantity of first or second patent flour put upon the market is relatively small compared with that of standard patent.

After the standard patent flour has been removed there is still obtained about 0.5 per cent of a flour called second clear, or low grade, which contains a high percentage of protein, but with a gluten of poor quality for bread making. Finally there is the so-called "red dog" flour, the lowest grade produced, which is secured mainly from the germ or embryo and adjacent parts of the wheat. It contains large proportions of protein and fat, but the proteids of the wheat germ are decidedly different from gluten in character and composition. Germ flour has poor agglutinating properties, and little power of expansion, and produces a poorly raised, dark-colored loaf.

The entire wheat flour included in this list was produced by removing a portion of the bran coat and grinding the remainder of the kernel. The Graham flour was made by grinding the whole of the grain, bran and all, no sieves or bolting cloths being used.

The Oregon wheat and the Oklahoma wheat were both ground at the Minnesota station in a small mill procured especially for the investigations. Only the standard patent, entire wheat, and Graham flours were produced from either of these wheats. It will be noticed that the Oregon wheat was much poorer in protein but richer in carbohydrates than the Oklahoma wheat, while the Minnesota wheat was about midway between. The analyses of these samples will serve to illustrate what has been stated above regarding the comparison of different grades of flour from different lots of wheat. Graham flour from even the Minnesota or the Oklahoma wheat had a larger protein content than the standard patent from the same wheat; but, on the other hand, the standard patent from either had much more protein than the Graham from the Oregon wheat. It is quite apparent, therefore, that a comparison of composition of the different grades from different lots of wheat is not a fair one.

Comparing the three grades of flour from the same lot of wheat, it will be noticed that in each case the proportion of protein was largest in the Graham and smallest in the standard patent flour, the entire wheat being between these two. On the other hand, the proportion of carbohydrates was smallest in the Graham and largest in the standard patent flour. Considering that these two nutrients are not present in flour in proper proportions for a well-balanced diet, there being an excess of carbohydrates and a deficiency of protein, it might seem from such a comparison of composition that the coarser flours would be the best. Before an adequate discussion of relative nutritive value

is possible, however, the digestibility of the three flours must be determined.

The breads from the different flours, when made in such ways as to afford comparison, bear the same relation to one another as the flours in respect to the proportions of nutrients. This is what would be expected in view of the fact, already stated, that except for the materials added in mixing the dough the composition of the bread depends entirely upon that of the flour. The analyses of breads included in the table will illustrate this. Thus, in the breads made from different grades of patent flour, that from the high-grade flour, which had the lowest protein content, had the least protein, while that from low-grade flour, which is the richest in protein, had the most. This was the case with the breads of which the analyses are given in the table, even though the proportion of water is highest in the bread from the low-grade flour; if the computations were based upon the dry matter of the breads the differences would be still larger. In the case of breads made from the different grades of Oregon and Oklahoma wheat, the values given are for dry matter, in order that the comparison may be absolute. These data show that in each case the Graham bread had the most protein and the least carbohydrates, as it was with the flours.

THE DIGESTIBILITY OF BREAD.

A knowledge of the digestibility of any food material is of prime importance for two reasons: In the first place, unless it is completely digested a portion of it does not serve to nourish the body at all, because only that part of the food that is digested and absorbed from the alimentary canal can be thus utilized, and, in the second place, some indigestible materials act as irritants in the alimentary canal, and while they may stimulate the excretion of the digestive juices they sometimes increase peristalsis, thus hastening the contents along too rapidly to permit complete absorption, with the result that nutritive material which otherwise might be absorbed and serve to nourish the body is lost with the indigestible materials. In estimating the nutritive value of a food material, it is therefore necessary to consider not only its composition, but also, and more particularly, the proportions of its different nutrients that are digested and utilized.

In connection with the nutrition investigations at the Maine and Minnesota stations, upward of 100 digestion experiments have been made with young, healthy men, with bread from different grades of flour ground from hard and soft wheats from Indiana, Michigan, Minnesota, Dakota, Oklahoma, and Oregon. In these investigations great care was given in each case to the securing of different grades of flour from the same lot of wheat, to the production of bread from the flours, and to all other details of the experiments, in order to secure

uniformity of conditions, and thus insure fairness and reliability in comparison. The results of these experiments therefore give very definite information regarding the relative digestibility of bread from different grades of flour.

The larger number of these experiments were made with Graham, entire wheat, and standard patent flours from wheats from different sections of the country. The averages of the results with these three grades of flour give the following as the proportions of nutrients that were digested from the different flours, these factors being commonly termed coefficients of digestibility: Standard patent flour, protein 88.6 per cent and carbohydrates 97.7 per cent; entire wheat flour, protein 82 per cent and carbohydrates 93.5 per cent; Graham flour, protein 74.9 per cent and carbohydrates 89.2 per cent.

The digestibility of the fat was also determined in some cases, but for the most part the results were believed to be too low, and are therefore omitted. The quantity of fat in bread is too small to permit of accurate tests of its digestibility. This is a matter of no importance, however, as bread is not considered as a source of fat in the diet. The very common custom of eating butter or some other fat with bread is in reality but a method of supplying this deficiency.

It will be seen that there is a considerable difference in the digestibility of the nutrients in the three kinds of bread, the variations in the protein being larger than those in the carbohydrates. For both nutrients the digestibility of the standard patent flour was the greatest, and that of the Graham flour was least. This is true not only for the averages of the tests with the different flours, but also for the individual tests. With some of the wheats the differences in the proportions digested from the different flours were not so wide as with others; and in some cases also there were very noticeable differences between the subjects with respect to the completeness of digestion; but with all the subjects, and with all kinds of wheat thus far tested, the uniform result was that the digestibility of the standard patent flour was the highest, that of entire wheat the next, and that of Graham the lowest. Concordant results were obtained in artificial digestion experiments.

Experiments were made with first, second, and standard patent flours to learn how these compare with one another, the digestibility of the nutrients as determined in these tests being as follows: First patent, protein 90.5 per cent and carbohydrates 98 per cent; second patent, protein 91.4 per cent and carbohydrates 98.7 per cent; standard patent, protein 90.3 per cent and carbohydrates 97.4 per cent.

Practically, there was no difference in these three grades of patent flour with respect to the proportions digested; and since the proportion of protein is much the same in all of them, they are about equal in actual nutritive value.

Differences in digestibility of the flours containing the branny portion of the wheat are sometimes attributed to the fineness with which

the coarse materials are ground. This is doubtless true to some extent, and may in part explain why whole wheat is more digestible than Graham, because the whole-wheat flour is somewhat more finely ground. But even when bran is reduced to a very fine powder it is not so well digested as flour, and its presence in the flour decreases rather than increases its nutritive value, because it decreases the digestibility. This was observed at the Minnesota station in some experiments with Oklahoma wheat. Bran removed in producing the patent flour was ground very fine, and was added to some of the flour, 14 per cent as much bran as flour, or about the proportion in which it was removed during the milling. This increased the protein content of the flour to 15.3 per cent as compared with 15.1 per cent in the flour without the bran. The digestibility of bread made from this mixture, as compared with that of bread from the same flour without the bran, was as follows: Bread with bran, protein 85.9 per cent and carbohydrates 93.3 per cent; bread without bran, protein 91.6 per cent and carbohydrates 97.8 per cent.

Thus, while the addition of the bran to the flour increased the proportion of the nutrients but a trifling amount, it decreased the digestibility very decidedly, so that the digestible nutrients in the flour with bran were only 13.2 per cent of protein and 67.5 per cent of carbohydrates, while in the same flour without the bran they were 13.8 per cent of protein and 71.1 per cent of carbohydrates. What little was gained in increase of nutrients by the addition of the bran was more than offset by the failure of the bran to be digested. It is evident, therefore, that the defective digestibility of the bran is not due entirely to imperfect grinding, though it is worthy of note that the bread from the mixture of ordinary flour and finely ground bran was more digestible than that from either Graham or entire wheat flour from the same lot of wheat.

A number of experiments were also made to study the effect of adding germ to patent flour. As in the experiments with bran, the germ removed in milling standard patent flour from Oklahoma wheat was finely ground and mixed with some of the standard patent flour in the proportion in which it was removed during the milling, the mixture containing about 93 per cent flour and 7 per cent germ. The digestibility of the nutrients of bread made from this mixture was as follows, the data for the patent flour without the germ being also given for comparison: Bread from mixture, protein 90 per cent and carbohydrates 97.6 per cent; bread from patent flour, protein 91.6 per cent and carbohydrates 97.8 per cent.

The digestibility of the protein in the flour with the germ added was slightly less than in the same flour without the germ, while that of the carbohydrates was practically the same in both. The digestible nutrients in the flour with the germ, computed by use of these results,

would give a trifle more protein and slightly less carbohydrates than in the flour without the germ. There was, therefore, practically no gain in nutritive value by retaining in the flour the germ that is ordinarily removed in the milling.

THE NUTRITIVE VALUE OF BREAD.

As previously pointed out, bread contains from 35 to 40 per cent of water. Since the remainder, about 60 per cent at least, is nutritive material, bread is really one of the most nutritious of the common foods, but few others equaling it in this respect. Bread supplies a large amount of carbohydrates, a moderate amount of protein, a small amount of mineral matters, and almost no fat. Since there is relatively an excess of carbohydrates and a deficiency of protein in wheat, bread could not serve alone for proper nutrition of the body, because an amount of bread sufficient to supply the requisite protein would furnish much more carbohydrates than necessary. In a mixed diet this discrepancy is of little importance, because the deficiency of protein is made up by such foods as meat or cheese. Bread and milk forms a much more suitable diet than bread alone. Where bread forms the whole or the main part of the diet, as it does among the larger number of poor people, and when flours of low protein content are used, the deficiency of protein is of much more consequence. In case of flours of high protein content this deficiency is of course smaller.

Various methods of increasing the protein content of bread have been followed, but only a few of them have been adopted for ordinary practice, because of a tendency to increase the cost of the bread too much. The use of skim milk instead of water for mixing the dough does not increase the cost of the bread very materially, but it does add appreciably to the protein content. A comparison of skim-milk bread with water bread, made from the same flour, is given in the table on page 354, showing that the skim milk increased the protein to the extent of about 2 per cent.

CONCLUSION.

In this discussion especial consideration has been given to the protein and carbohydrates, and no mention has been made of the mineral matters, among which are the phosphates of the wheat so popularly considered of especial virtue. This omission has been intentional for the reason that as yet not enough is known concerning the metabolism of mineral matters in the body to warrant a discussion of the value of those contained in the flour. Such investigations as have been made suggest that the supply in the ordinary diet is more than sufficient to meet the demands of the body. In the experiments it was observed that the quantity of mineral matters in the feces was from a third to a half as large as those in the bread, but it can not be said how much of

the excreted material pertained to undigested bread and how much was from other sources. In view of such lack of knowledge it would be futile as yet to compare the three grades of flour with respect to their value as sources of mineral matter.

While the coarser grades are not more nutritious than the finer flours, there are many cases in which they are especially desirable, as, for instance, for persons of sedentary habit and occupation, because their stimulating of the alimentary tract may help to procure a larger secretion of the digestive juices and also to overcome a tendency to constipation. This, however, is a purely physiological action, and should be considered apart from the nutritive value. Finally, it may be said that wheat flour of all the various grades is one of the cheapest, most digestible, and most nutritious of human foods, and well worthy of the high estimation in which it is generally held. The use of different sorts of wheat flour is a convenient way of giving variety to the diet, a matter which is of no little importance.